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ABSTRACT

Researchers examined data from perceptual instruments administered to participants (36 undergraduate education students) during and following problem solving sessions. Think-aloud and interview analysis resulted in combining examination of the problems with the motivations and perceptions of the problem solvers. The nonemergent qualitative design revealed themes that affected the participant's solution paths. Conditions that positively influenced the use of analogical thinking were identified as enablers; those that impaired its use were labeled as inhibitors. Enablers included positive perceptions of the self as problem solver, active engagement in the problem, perceived familiarity with the domain of knowledge, and the accurate recall and use of problem solving strategies. Inhibitors included poor self-efficacy for problem solving, recall of negative experiences, lack of background knowledge, and inaccurate application of the problem solving principles. The participants' comments revealed connections with other theory and research on problem solving and learning transfer. Future research is implicated in areas of the effects of problem-solving instruction within a contextual domain. (Contains 2 tables and 29 references.) (Author/SLD)

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Cognitive Processes in Problem Solving via Think-Aloud and Interview Analysis

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Abstract

Researchers examined data from perceptual instruments administered to participants during and following problem solving sessions. Think-aloud and interview analysis resulted in combining examination of the problems with the motivations and perceptions of the problem solvers. The non-emergent qualitative design revealed themes that affected the participants' solution paths. Conditions that positively influenced the use of analogical thinking were identified as enablers; those that impaired its use were labeled as inhibitors. The participants' comments revealed connections with other theory and research on problem solving and learning transfer. Future research is implicated in areas of the effects of problem-solving instruction within a contextual domain.

Cognitive Processes in Problem Solving Via Think-Aloud and Interview Analysis

Transfer and application of knowledge is a major goal of the educational process. The ability to draw analogies from one problem solving situation to another is intertwined with the ability to transfer learning from one situation to another. Research studies have considered the many aspects surrounding the phenomena regarding this ability. Some have concentrated on the circumstances that promote analogical problem solving. Yang and Wedman (1993) and Hsu and Wedman (1994) linked selected instructional factors (e.g., problem representation, content treatment, and practice opportunities) to analogical problem solving performance. Visual representation, use of a principle rather than procedural steps in problem solving, and practice opportunities increased the use of analogical thinking in some conditions. Chen, Yanowitz and Daehler (1995) investigated whether "instantiating" a principle, through external or internal means, affected transfer of a solution to a newly presented, but related, question. In one of their experiments, the abstract principle which applied was presented to the subjects of their study accompanied by an example which was either given, or required from the subject. Both conditions facilitated the transfer.

From a different tact, Okagaki and Koslowski (1987) researched dimensions of analogous problems that affect the transfer of useful information. They delineated the differences between analogs that provide "physical models," those with situational similarity, and those that transfer a principle from one context to another, or "conceptual models." Ohlsson (1993) described the conceptual model as an "abstract schema" - a structure applied when going beyond "immediate experience"

to find a solution. Ohlsson further proposed that there are different types of these schemata. He classified the schemata according to problem solvers' purposes, some of which could be to describe, explain, argue, or quantify.

Salomon and Perkins (1989) proposed use of these types of analogs as a result of "high road transfer," meaning that the abstraction is "mindful" and can be described as "forward-reaching," looking forward to the time that the present information could be applied, or "backward-reaching," a purposeful search for knowledge already gained. This research regarded the intent of the problem solver as a factor. Furthering this perspective, Perkins, Jay, and Tishman (1993) discussed seven "dispositions" of problem-solvers that characterize "good thinking." In their research, they described qualities such as the "disposition" to be open-minded and explore new ideas, to sustain inquiry, to make connections with background knowledge and experiences and to reason inductively. Analyzing participants' problem solving processes, Wedman, Wedman, and Folger (1996) found that successful problem solvers were more efficient, following predictable patterns when solving analogous problems.

The current study integrated discussion of the problems with the motivations and perceptions of the problem solvers. The data from this study identified qualities of both and moreover, the effect of their interaction on the transfer of the analog to the new, or target, problems. While the research team continued focus on the participants' cognitive processes during the problem solving sessions, they broadened the data base to include interviews with the participants. These interviews dealt with the participants' reflections on their cognitive processes and on the problems they had been asked to solve. What effect did the participants' perceptions of the problems and themselves as problem-solvers have on their ability to solve the target problems? Were there identifiable themes in the think-aloud and interview data that

would clarify our understanding of the cognitive processes used during the problem solving experience? Reliance on the participants' perspectives led to a more exploratory and descriptive research approach.

Research Design

Since all of the interview data had been collected before being analyzed, a nonemergent qualitative research design evolved as the most applicable approach to the investigation. The outcomes were derived inductively from the data, by the "systematic building of homogeneous categories,"(Maykut and Morehouse, 1994). The research team worked together in order to reduce single researcher bias as the data was analyzed. An *audit trail* (Lincoln and Guba, 1985) was provided through the use of HyperQual 4.3 (Padilla, 1991) in doing constant comparative method analysis (Glaser and Strauss, 1967). HyperQual coded each unit of data to its source, allowed for research notes, tagged the units of data as identified by the researcher, and sorted the units into stacks, much like stacks of 3x5 note cards. After further discussion, the stacks could be resorted through the use of filters, combined, or rearranged allowing discovery of new themes in the data.

Method

Although the research team was interested in individuals' problem solving performance, the study focused primarily on the participants' reflection on problem solving processes as revealed by the think-aloud protocols and subsequent interviews.

Participants. The participants in this study were thirty-six undergraduate education students (4 males; 32 females) enrolled in two sections of a reading methods course at a major mid-western university. These students, juniors and seniors, were above average in terms of academic ability (GPA = 2.75 or higher). They had been admitted to the teacher preparation program in the college of education. Their degree majors

included early childhood, elementary, secondary, speech, and special education. Inclusion in the sample was a requirement of the reading methods course as a follow-up experience in the use of think-alouds.

Instrumentation. Based on the work of Hsu and Wedman (1994), the research materials consisted of six versions of self study materials involving analogous problems. Including essentially the same information and problems, the materials differed in terms of : 1)content treatment (principle vs. procedure for solving a problem); and 2) practice opportunity (0,1 or 2 practice items with feedback).

In terms of content treatment, three versions of the materials consisted of a problem-solving principle and an example illustrating the principle. The principle used in the materials was: "to destroy an object, when direct application of a large force is harmful, disperse the attacking forces and have them converge at the object." In the other three versions, the content consisted of a problem-solving procedure and an example illustrating the procedure. The procedure used in the materials accomplished the same task as the principle:

Step 1. Determine the required resources

Step 2. Determine the situational constraints

Step 3. Distribute resources based on constraints

Step 4. Apply distributed resources

In terms of amount of practice opportunities, two versions of the materials contained no practice opportunity; two versions contained one practice opportunity; and two versions contained two practice opportunities. All practice opportunities included feedback in the form of providing the correct answer to the practice problems.

An instrument was developed to assess the subjects' analogical problem solving ability. This instrument consisted of four problems, two of which were analogous to the problems included in the self-instructional materials. The other two

were not analogous and served to mask the potentially obvious relationship between the source and target problems. Table 1 provides a listing of the problems used in the study, their role, location, and source information.

Insert Table 1 About Here

The *perception instruments* included the think-aloud procedures and interviews. These provided information regarding the individuals' cognitive processes during problem-solving and their reflections on the problems and problem-solving in general. The think-aloud procedure and unstructured interview were the primary data collection source. The interview as a data source is a form of discourse shaped and organized by asking and answering questions, a joint product of what interviewees and interviewers talk about together, with the data source used by researchers being the record made and used in analyzing and interpreting. The record is representative of the talk. (Mishler, 1986)

The primary question in the interview was "Have you ever solved problems like these before?" Other questions emerged from the answers given to the primary question and from think-aloud information. Questions concerning solutions of daily problems, similarities and differences between the problems in the study and problems in daily life, and differences and similarities in solutions to these problems directed the informal conversations. The participants often gave examples when answering these questions which led to further conversation about how they solved problems in general. When necessary, the interviewer probed with questions such as "What do you mean?" "Why are you doing that?" and "Could you tell me more?" to help clarify the participant's meaning.

Data Collection Procedure. The participants were told that they were going to participate in a class exercise that would help them learn to use think-aloud protocols

to identify and understand reading miscues. Think-Aloud Interview Schedules were posted in the classrooms and the participants signed up for times that were convenient for them. The schedule covered seventeen weekdays, with one and one half hour blocks of time arranged for each interview. The participants were randomly assigned to one of six groups and received the appropriate version of the research materials. They were also informed that they were participating in two experiments, while in actuality there was only one experiment with three parts. Part One consisted of written instruction on how to solve a given problem; the instruction included the general principle or procedure, an example illustrating the principle or procedure, and zero, one, or two practice opportunities involving analogous problems. Part Two was the assessment of the analogical problem solving performance. Part Three was the follow-up interview regarding the participants' problem-solving experience, their daily problem-solving experiences, and their reflections on problem-solving. Data collection was done by two research assistants who had been previously trained to administer the problem instruments and conduct think-aloud and interview procedures. The sessions were audiotaped and transcribed.

Data Analysis Procedure. The thirty-six think-aloud protocols and interviews were analyzed using an approach to data analysis described by Strauss and Corbin (1990). In this approach, the researcher is primarily concerned with describing accurately what she or he has understood. Using some amount of interpretation, the data is reconstructed into a narrative form that represents the reality of the participants' experience. This type of analysis has been referred to by Belenky (1992) as "interpretive-descriptive" and seems to fit the analysis that has emerged in the current study.

In order to work efficiently and easily with the large amount of data that had been transcribed from the think-aloud and interview procedures, the research team decided to use a software tool. HyperQual 4.3 is a program that handles the

mechanical part of qualitative research by assisting in the recording, management and analysis of data, particularly text data. It adapts the features of HyperCard (Apple Computer, Inc.) to the needs of the researcher, so that he or she can easily enter field data and "tag" or code chunks of data, which can then be sorted into relevant categories. (Padilla, 1991)

In using HyperQual 4.3 (Padilla, 1991), it was first necessary to enter the transcribed material from the think-aloud protocols and interviews as word processor documents (Microsoft Word 6.0). Research notes regarding possible categories were made on the General Project Face Card. Then, the documents were transferred as text to the HyperQual program. With each transfer, the researcher made notes on information related to the specific interview such as the name of the interviewer, the participant, and the information regarding setting of the interview.

In preparing the data for analysis, Maykut and Morehouse (1994) suggest that the pages of data be coded to their source before the data is unitized for meaning. This procedure proved helpful when study of a unit of data in its fuller context was necessary. The HyperQual program automatically coded each unit of data to its source in the original interview/think-aloud stack. The data was unitized (Lincoln and Guba, 1985) by highlighting a *chunk of text* and clicking the *Tag and Stack* button. At this point the unit of thought was tagged with one or more descriptive words, to make it easily identifiable in a stack. These descriptors ranged from capsules such as the name of the problem discussed such as "Red Adair" to response types such as "emotional," or even the ID number of the participant. The unit of thought was then placed on a *card*.

The researcher then began use of the constant comparative method of analysis (Glaser and Strauss, 1967; Lincoln and Guba, 1985) in order to allow themes to emerge. This method of analysis is an inductive approach in which the categories for qualitative data are not pre-determined by the research team.

Instead, "what becomes important to analyze emerges from the data itself," (Maykut and Morehouse, 1994). The process of constant comparative analysis required a coding of the units of data through the use of the descriptors into categories. As each new unit was tagged it was compared to all of the others and grouped with those that were similar. Gradually, several thematic *stacks* were created and substantive categories emerged. The research team then reviewed the categories for "overlap and ambiguity (Maykut and Morehouse, 1994: 142)." Some of the categories were adjusted and redefined. Units of data that had been regarded as miscellaneous, not meeting the descriptions of any of the previously set categories, were re-examined. The research team then studied the substantive categories as they related to one another and developed propositions that would help us understand the focus of our inquiry.

Data Source. There were three sources of data used in this study. One was the participants' performance on the two (*initial* and *subsequent*) target problems. This performance was scored by two raters; interrater reliability was 86%. Another source was the information provided during the think-aloud procedure as the participants worked through and came to a solution on the problems. The third source of data was the participants' response to the unstructured interview questions.

Outcomes

The scoring of the initial and subsequent problems was done according to a system devised by King (1988). Each of three elements of the analogy, division of the "attacking forces," distribution of the force, and simultaneous attack of the divided force, was scored as one point. Of the thirty-six participants, two participants scored all three points on the initial target problem, but only one point on the subsequent target problem, their scores being recorded as (3,1). Two

participants did not score any points on the initial target problem, but used all three elements in their answers on the subsequent problems (0,3), and two participants used none of the elements in solving the initial target problem, but did use one of the elements in solving the subsequent target problem, scoring (0,1). Seven participants applied all three elements to solving both the initial and target problem, resulting in the notation of (3,3), while eight did not score any of the points on either target problem, receiving scores of (0,0). Eleven participants scored at (3,0), and one participant each scored at (2,2),(1,0),(2,3), and (3,2). These scores resulted in a general idea of the analogous problem solving ability of this group of participants. Other quantitative data derived from the assessment materials provided insight into problem solving patterns of successful problem solvers (Wedman, Wedman, and Folger, 1996). However, the perception instrument data yielded identifiable themes concerning the cognitive processes of all of the participants during and subsequent to the problem solving experience.

Both the participants' perceptions of themselves as problem-solvers and their interpretation of the problems affected their ability to solve the target problems. Many talked about the experiences they had had as problem solvers. Some expressed positive or negative views of themselves in this role. Participants who expressed a positive view of themselves solved one or both of the target problems. Some of the comments reflective of this thinking were:

P1 "I like to solve little pieces and puzzles and things like that. I'm kinda slow at it, but I like the thinking involved in it." (3,3)

P2 "I just have always been really fast at problem solving." (3,3)

P3 "I'm the one who always comes up with the ideas." (0,3)

Participants' negative feelings toward their ability to solve the problems may have contributed to their difficulty in making the complete analogy. Examples of negative comments were:

P4 "I'm sure that one isn't how you'd solve it." (0,0)

P5 "I don't know how to solve this problem...I'm thinking that my solution's probably not right, but they were a good attempt." (1,0)

P6 "I used to be one of those kids that hated word problems...I wish I would've been able to do more. I just avoided them like the plague when I was little, actually, but I'm getting better." (0,3)

Other comments related these positive and negative feelings to past experiences in problem solving. Several participants who expressed positive feelings about themselves as problem solvers also revealed positive experiences. Models which involved looking for more than one way to solve a problem were mentioned.

P7 "...in seventh grade, I did problem solving bowls...they would give you huge problems and model steps you could take..." (3,0)

P2a "...I was in the gifted program and so they did a lot of problems with us when we were younger, to push us to look at things a different way...so I've always just had that way of looking at things ...trying to find a solution...we were encouraged to figure out different ways of solving it..." (3,3)

Conversely, a participant who had difficulty solving the target problems talked at length about a negative experience. This participant was actually discouraged from thinking divergently, as the continuing conversation reveals. Trying to gauge the effect of this experience on the participant the interviewer probed.

P8 "I had a really hard teacher and she had one way of doing it and that was it...now I'm taking Math this semester for teaching and it's so different from what I've ever had; it just seems totally different for me to try and think on my own and think up different ways when all I know is you do it this way or it's

going to be wrong....I was really frustrated most of the time...because I would do my homework and the answers were in the back of the book, so I could check my answers....I knew I was getting the right answers but then I would take it to class and half of them would be wrong....had conferences and stuff...I couldn't see that her way was going to be that way everywhere."
"So, did you internalize that; did you try to do it her way?"
"For a long time, I really tried hard to do it her way...I could do the simple problems her way, but after that, they got tough, so I started thinking on my own and how to rearrange the steps and then that's when I had trouble." (0,0)

This previous experience contributed to this participant's inability to apply any element of the analogy to either target problem.

Participants also made observations about the study problems, and their influence on their problem-solving. Majority of the comment on the content of the initial target problem stemmed from a confusing sentence structure which seemed to present ambiguous information. More participants verbalized this confusion but continued to solve the problem than did not.

P9 "Okay, there's another problem. It says the smaller hoses were not shooting it quickly...I don't know if that meant that the foam can't actually get through the hoses fast enough...or if there's not enough hoses to attack it quick enough..." (3,1)

P10 "'The small hoses that were available could not shoot the foam quickly enough to do any good.' I'm thinking does that mean that the small hoses by themselves, or the small hoses working all together weren't enough, because if they were all used, it might be enough." (3,3)

P3a "Does it say 'cannot shoot the foam quickly enough?' That really would limit the idea of doing all of them at the same time...it depends on if its the hose that has the problem of squirting or if it's the amount coming out..." (0,3)

The last participant quoted above was able to successfully apply all three elements of

the source analog to the subsequent target problem. This fact implied to the researcher that the confusion with the sentence impaired the application of the same elements to the initial target problem

Another factor in the participants' solution of the analogous problems was lack of familiarity with the problems' content. Although it also occurred with the initial target problem, the *Red Adair*, this was more observable in the solution of the subsequent target problem, *Radiation*. In fact, seven participants who had successfully applied the analogy to solve the Red Adair problem voiced a lack of familiarity with the content of the Radiation problem. Exemplars were:

P11 "I'm not very smart in this area." (3,0)
P12 "On this one I don't feel like I have enough information...I don't know what other options I as the doctor would have...probably other medical options, but I don't know any..." (3,0)

Motivation to solve the problem, emotional interference, and the inability to accept responsibility for a solution also affected several participants' solutions. At the other end of the spectrum, more personal involvement detracted from some participants' ability to access the source analog. The following responses to interview questions concerning the problem content revealed these effects.

P12a "...the idea of taking across an army really doesn't pertain to my life."
"No?"
"Not at all...I bet I could have gotten more involved if you would have given me a situation about a kid...Where would you place him?"
"So it helps you solve a problem if you are more involved in it?"
"If I am more involved in it...I think it means I am interested in what's going on there. (3,0)

P13 "I guess what I keep thinking of is my grandmother who passed away a year ago, of a brain tumor. And I keep going back to that." (0,0)

P14 "My aunt has a malignant tumor in her brain...I'm not sure there is a way to solve this problem."

"Does this problem remind you of any of the other problems?"
"Just this one. I don't know. I wasn't thinking about that. I had my aunt and my grandma go through my head. I don't know." (3,0)

After the score was recorded, the interviewer tried to redirect the latter participant's thought processes. The participant was able to refocus on the principle and apply the analogy when prompted. During the interview session, the researcher returned to the Radiation problem in order to allow the participant to reflect on the solution.

P14 "If you think about the principle that you used on those other problems, could you use that principle on this one?"
"I think about it that instead of how the other ones...all the armies go at one time to the whole government, so they split it up into little ones.. and then they all reached their common goal at one time and then they...this you could even break it up in stages...or I guess you could have a whole bunch of lower rays coming. I think you could do it that way as well...a whole bunch of lower rays so that they are forces..."
"Like on that last problem, where the thought came to mind about your grandmother and your aunt, how did that affect, you think, your ability to solve the problem?"
"I think that you become more one-sided. As I was reading it, there was probably a lot more thought of what was actually going on in my family that I was reading into the problem, so that put a damper on my openness toward it, just because of the experience I had, and even if there were other ways to solve the problem, I was only thinking one way...." (3,0)

The participant (P14) easily used analogous thinking to solve the initial target problem and applied the analogy to the subsequent target problem when her thoughts were redirected to the principle. The observation that personal involvement interfered with the participant's ability to use the source analog effectively gained credibility.

The Radiation problem's content caused another interpretation that affected participants' solution. Three participants translated the problem into one involving the ethics of the medical situation. The ethical viewpoint did not yield a solution. Some comments during the think-aloud that reflected this concern were:

P15 "...more of an ethical thing...I have to think of the patient...it becomes a harder problem.."(0,0)

P11a "...It's the patient's decision. It's a problem for the doctor only in that he's got to convey that message and let the patient make the decision...I can't make that decision." (3,0)

The latter participant was able to apply the analogy in the initial target problem, but did not when she felt the problem was out of her hands. The responses in these conversations reflected the participants' perceptions of themselves as problem-solvers and of the perceived content of the study problems. These perceptions influenced many participants' cognitive processes as they planned solutions.

The researchers also identified themes in the think-aloud and interview data that led to a better understanding of other cognitive processes involved in analogous problem solving. Participants who recalled in the context of problem-solving the procedural steps or the analog principle solved the target problems with some success. In the interview, the researcher asked about the use of the principle or procedure. During the think-aloud, several participants spontaneously reiterated, in some form, the principle or procedural steps. In fact, the comments made during the think-aloud procedure often appeared to be their verbalization of the "mapping process." Research has described this process of constructing correspondences between the source analog and the target problem as being central to analogical thinking (Gick and Holyoak, 1980; Holyoak, 1984; Holyoak and Koh, 1987; Holyoak and Thagard, 1989). The interview responses provided further reflection on this process. Some participants described features of the target problems in order to match features of the analog. This allowed them to apply the principle or procedure. When a participant (P17) misinterpreted the principle, however, the analog was disrupted.

P16 "...it's always one big, there's always an object or somewhere you want everything to meet at the same time, but high dosage, or high concentration of that is harmful, so you have to break it up. You have to bring in smaller groups from all different sides and have them meet." (3,2)

P14a "...the government and with the fortress and with the cancer. I thought that they could all be broken up and the little things could solve the great big things.." (3,1)

P17 "...the first three all had a similar thing; the tanks, the armies, and the fire hoses...if you combined your effort and it was simultaneous...you could divide and conquer..." (3,0)

Those who were given the procedural treatment of the study materials commented as follows, "mapping" the procedural steps onto the content of the target problems. In the last conversation (P19), the participant recalled the procedure, but was not able to complete the process, and did not solve the problem.

P18 "Your resources are the foam, the foam that can be dumped on the base. The constraint is that there is not enough foam available..." (2,2)

P11b "Did you find that any of the earlier problems helped you solve any of the later problems?"
"I think so, because I thought about the resources...kept coming up, and I kept thinking what are my resources and what's the situation that I've got to deal with...I think that helped to organize my thoughts." (3,0)

P19 "Does this problem fit the pattern - how you were doing the other ones with your steps?"
"It kind of does. It tells you the first step is what they want to accomplish. And the second step tells you they can't operate. And then the high intensities will destroy healthy tissues, but the lower won't do anything...I guess this three that doesn't really..."
"You couldn't do step three? Distribute?
"I guess you can't really distribute anything." (3,0)

When the participant verbalized the analogous relationship between either the source analog and the target problems, or between an outside analog and the target problems, he or she was generally successful in solving the initial and/or subsequent target problem. The comments came as responses to direct prompts during the interview and as spontaneous observations during the think-aloud procedure. Several participants drew analogies to situations outside of the study instrument, including those used to solve the distracter problems. The last two responses in the next group of exemplars (P21 and P10c) revealed the connections participants made with the source analog.

P10a "It's like a cartoon that I saw...a tortoise and hare cartoon and there are hundreds of turtles and they want to beat the rabbit..so they each take spots along in the race...that way the turtles win, so if I were the twins, that would be what I would do." (3,3)

P20 "...the identical twins. Something happened like that when I was in eighth grade...the teachers never did know who they were...their handwriting was close to the same and most of the tests were multiple choice, anyway, so...the other one could go in and do the other one's test, and they both graduated with A's..." (3,3)

P10b "I saw 'Fires of Kuwait.' It's a movie at the Science Center in the Omnimax Theater. When they were trying to do it..."(3,3)

P20a "Saudi Arabia? I've seen movies on oil well explosions. They used nitroglycerin, dynamite explosions to blow out...so, it's still a huge force, and that and just watching the fire shows give me that kind of idea." (3,3)

P21 "I think that this is similar to a couple of the other ones that we did in that you're going to have to attack the tumor from different angles at lower intensities," and "This is very similar to the first and the third problems." (2,3)

P10c "It seems like the beginning problem, the practice problem..." (3,3)
"...similar to the first problem I think, with the fortress...you had to divide your army to conquer that fortress and this is similar to me in that you're going to have to group all of the small hoses together to put out one fire." (2,3)

The themes evolved from the perception instrument data allowed the researchers to understand that there were many cognitive processes at work during the participants' problem solving experience. These processes involved conditions that influenced the participants' analogical thinking.

Discussion

The participants' cognitive processes during problem solving either enhanced or impaired the use of analogical thinking to solve the target problems.

Insert Table 2 About Here

Table 2 summarizes the effects of these thought processes, or conditions, on the actual solution. From the data, the researchers identified seven factors which influenced the participants' problem solving processes. Each factor held enabling or inhibiting values.

Conditions that aided the problem solvers in noting analogous relationships or *enablers* were:

- positive perceptions of self as problem solver
- recall of positive problem solving experiences
- active objective engagement in the problem
- interpretation of problem content consistent with the intent to solve
- recall and accurate use of procedural steps or the applicable principle within the context of the problem
- perceived familiarity with the domain of knowledge
- active objective engagement in problem solution

- Identification and accurate application of the principle or procedural steps
- recognizing analogous relationships between target problems and either the source or an outside analog

The recall of positive experiences often resulted in a positive self-image as a problem-solver, seeing oneself as quick to solve, a source for ideas. Perceiving problem solving as an enjoyable, often social, experience enhanced this attitude. Models of problem-solving that tolerated, even encouraged, differing avenues of thought profited the problem solver. Motivation to become involved in the solution was provided by previous experiences that were referenced by the problem-solver and used as analogs. Participants who perceived the problems as relevant and realistic, and approached their solutions objectively became actively engaged. The content also had an enabling effect if the participants had some degree of familiarity with that knowledge domain, or did not perceive the lack of familiarity as an impediment. When participants found the content information to be consistent with the solution path, whether it was through use of the principle or procedure, an enabling effect occurred. Recalling the principle or procedural steps allowed the participant to use a mapping process that usually clarified the solution path. Verbalized analogous relationships instantiated the principle or procedure, much like recalling useful examples (Chen, Yanowitz, and Daehler, 1995). When participants made an outside analogy during solution of a distracter problem, it indicated that analogous thinking was already in place in the participant's repertoire of problem-solving methods.

Table 2 also identifies values that inhibited or made conditions less likely for the use of analogical problem solving. These were:

- poor self efficacy in the realm of problem solving
- recall of negative experiences in solving open-ended problems
- Content interpretation that perceived information as incomplete or ambiguous

- expressed lack of background knowledge for the content in the problem
- recall of emotionally charged information related to the content of the problem
- translation of the question presented in the target problem
- inaccurate mapping of procedural steps or misapplication of the principle

Negative experiences with problem solving resulted in difficulty for the participants in being able to see themselves as capable problem solvers. Having "avoided them like the plague" as children for whatever reason, or having had experiences that discouraged any independent or creative thinking, these participants felt that their solutions were "probably not right." The lack of background or "domain specific knowledge" for the problem is thought to limit the transfer of knowledge from a known situation to a novel one (Chi, Feltovich, Glaser, 1981; Simon, 1979). The ability to use analogical thinking to solve the target problems would also be inhibited. This verbal observation could also be seen as concentration on "surface features of the problem," an aspect of novice problem solving researched by Schoenfeld and Herrmann (1982) and Silver (1979). In recent research, Wedman, Wedman, and Folger (1996) found that the unsuccessful problem solvers spent less time reading the Radiation problem than did their successful counterparts. Lack of background for the content may have limited the time spent reading and influenced the engagement in the problem. A meaningful connection to reality aided motivation to become engaged in solving a problem. However, recalling personal or emotionally charged information related to the problem content inhibited the engagement in the subsequent target problem. The distressful thoughts took precedence and effectively blocked the participants' cognitive access to the analog. Dimensions of analogous problems thought to promote transfer of useful information include the physical similarity of the problems, the similarity between the goals of the problems, and the similarity between the questions asked (Okagaki and Koslowski, 1987). Inability to apply the procedural

steps, noting that nothing could be "distributed," or misrepresenting the principle, as when the meaning of "divide and conquer" was misconstrued, disrupted the similarities between the source analog and target problems. This was also the effect of transforming the subsequent target problem so that it addressed ethical issues. The question's translation from "What would you do to solve the problem?" to "Is the solution to the problem the doctor's responsibility?" submerged the characteristics of the analogous relationship. The participants could not readily access the analog.

Table 2 also relates the interesting value of ambiguous information noted by participants in the initial target problem, The Red Adair. For most, the ambiguity had no effect on their ability to solve the problem using analogous thinking.

Implications

The discussion of these *enablers* and *inhibitors* to analogical thinking raised several implications for the researchers. Some of these implications apply to the uses and possible effects of instruction in problem solving. Others point the way to future qualitative research in this area.

Educational Implications. Students need positive problem solving experiences that encourage an open attitude toward ways to solve problems . Several of the participants mentioned group problem solving - in gifted education classes, problem solving bowl teams, retreat activities. This use of the group dynamic may have helped them to view problem-solving in a more social and positive light.

Part of the cognitive process in problem solving is dredging up what is already known to apply to the new situation. If there are no accessible or applicable schemata, problem solvers are at a disadvantage, especially if the lack of schemata takes the focus away from the principle or procedure that could apply. We then address the question, "What kind of background do we provide students in problem solving?" According to research, an effective problem solver needs both domain

specific knowledge and background in the general heuristics of problem solving (Perkins and Salomon, 1989). It is impossible, however, to make sure students are knowledgeable in all domains in which they may someday encounter a problem. That leaves us with the option to examine with students the heuristics for types of problems in domains of knowledge familiar to them.

Taking this direction, the Cognitive Acceleration through Science Education (CASE) project, a two-year program designed for grades six and seven, used activities based on Piaget's formal operations (Inhelder and Piaget, 1958) to measure the effect of problem solving instruction. The "science-like" activities induced "cognitive conflict" in students. The teachers encouraged their students to reflect on their own thinking and applied the thinking patterns developed to science and other subject areas. The experimental and matched control groups were followed for two and three years after the end of the intervention. At the end of the tenth grade the students took the United Kingdom's national public examination. Results indicated "significantly higher grades" in the subjects of science, math, and English for the experimental group. The CASE project results indicated that "large-scale far-transfer" did occur for these students. (Adey and Shayer, 1993) The original researchers claimed that the enhancement of the students' formal operational thinking caused the transfer (Adey and Shayer, 1993). Other explanations explored at the AERA annual meeting (1996) included ideas concerning confidence building (Leo and Gallaway, 1996), students' views of their own intelligence (Dweck and Bempechat, 1983), and aspects of "thinking dispositions" (Perkins, Jay and Tishman, 1993). Several of the propositions derived from the themes that emerged in the current study's perceptual data reflected these ideas. Certainly, the participants' views of their own capabilities as problem solvers affected their ability to successfully apply the analog. Also some of Perkins, Jay and Tisman's (1993)"dispositions" for good thinking were apparent. The tendency to verbalize lack of background knowledge, to refer to experiences that

provided analogs, to evaluate the effectiveness of solutions and to reflect on the problem-solving exemplified "key abilities" for these "dispositions."

Participants also had difficulty applying the principle or procedural steps in the source analog if they voiced a lack of familiarity with the content of the target problems. In those circumstances, participants expressed the feeling that there was not enough information in the problem, uncertainty about their solutions and lack of interest in the problem. Highly personal content in a problem elicited responses that dwelt on distressful experiences. Focus switched from the analogous relationship to the frustration or distress of the experience. A source analog used in teaching a problem-solving principle or procedure needs to be meaningful to the problem-solvers, but not to the point of emotional distraction. This observation implied that instruction in problem solving must fit the students psychologically as well as cognitively.

Surface features in a written problem, such as unclear syntax or semantics, distracted some participants from the analog. More adept problem solvers ignored the inconsistencies. They made the conditions in the new problem fit the analog in response to their expectations. For an analog to have instructional value, problem solvers need to be actively engaged in the problem solving. As one participant commented, "I was just getting into the frame of mind, you know, a way of looking at it and then afterwards, on my four problems, I already had it in my head and I was already starting to do it as soon as I read it. It makes you more active when you read..." This observation exemplified "forward-reaching" transfer (Salomon and Perkins, 1989).

The problem-solvers' ability to restate, or recall, the analogous principle or problem-solving procedure also indicated the degree of completeness in the problem solvers' correspondence from the source analogy to the new problem situation. It may have aided problem solvers to verbalize this correspondence in order to clearly

and accurately apply the analogy. This observation, as well as other implications for instruction provided by the current study, fostered possibilities for future research.

Research Implications. Extensions of this research could take many directions. Explicitly, the current study identified several cognitive processes that either *enabled* or *inhibited* the use of analogical problem solving. Researchers could focus on a more diverse group of participants and narrow study to one of these aspects, such as the effect of personal involvement. Educational implications added other perspectives. Research could investigate the characteristics of effective analogical problem solving instruction. Participants described previous experiences with solving open-ended problems in social contexts - participating in gifted programs, group problem solving during retreats and joining parents in solving newspaper puzzles. A study could be made of the effect of learning to problem solve in groups and the group dynamics involved. This could be connected to assessment projects being developed in some states which emphasize the authenticity of problem solving as an evaluation instrument for many academic areas. Effective learning strategies in academic areas, especially literacy, are very often imbedded in social context as well. Additionally, reading and writing may share many of the *enabling* and *inhibiting* cognitive processes with those identified by the current study. Future research could explore the effect of using these conditions to practice analogical problem solving on students' reading and writing processes.

Conclusion

In this research, substantive themes evolved from looking qualitatively at data collected from perceptual instruments. The participants' perspectives and reflections revealed many connections with other research on problem-solving and transfer of learning. Analysis of the data identified cognitive processes as *enablers* or *inhibitors* to analogical problem solving. Consideration of these processes held implications for

teaching principles of problem solving within a contextual knowledge base and for future research into the effects of such instruction. A more general conclusion to be drawn from this and other research mentioned is that qualitative methods clarified the cognitive processes of problem solving. Researchers listened to the thoughts of problem solvers traveling their unique solution paths, and to their reflections on that experience. Holding those thoughts still on paper for a deeper analysis, researchers arrived at a better understanding of the cognitive processes involved and the conditions related to problem solving.

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Table 1. Research Problems, Role, Location, and Source Information

Problems	Role	Location	Source Information
The General	Source problem	Self-instructional materials	Gick&Holyoak, 1983
The Commander	Practice problem	Self-instructional materials	Gick&Holyoak, 1980, 1983
Parade	Practice problem	Self-instructional materials	Gick&Holyoak, 1980, 1983
Red Adair	Initial target problem	Assessment instrument	Gick&Holyoak, 1983
Radiation	Subsequent target problem	Assessment instrument	Gick&Holyoak, 1983
Wine Merchants	Distracter problem	Assessment instrument	Gick&Holyoak, 1980
Identical Twins	Distracter problem	Assessment instrument	Gick&Holyoak, 1980

Table 2. Implications for condition effects on analogical problem solving

Factors	Values	Implications
Self efficacy in problem solving	Postitive view Negative view	Enabler Inhibitor
Past experience in problem solving	Alternative solutions encouraged Divergent thinking discouraged Social experiences related	Enabler Inhibitor Enabler
Content interpretation	Ambiguous information Incomplete information Information consistent with intent	No Effect/ Inhibitor Inhibitor Enabler
Problem content domain	Novel Familiar	Inhibitor Enabler
Engagement in problem solution	Active objective engagement Emotional interference Translation of problem question	Enabler Inhibitor Inhibitor
Use of principle and procedural steps	Principle/procedure identified Principle/procedure used inaccurately	Enabler Inhibitor
Analog source	Source or practice problem Life experience	Enabler Enabler